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Vision and proprioception in action monitoring by young and older adults

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ABSTRACT

Discrimination of proprioceptive and visual spatial information is a prerequisite for the learning of visuo-motor transformations. This study investigated the individual's capability to discriminate the directions of seen cursor motions and felt hand movements under a visuo-motor rotation paradigm and its age-related variation. Young and older participants performed 3-stroke arm movements on a digitizing tablet without seeing their arm. The visual feedback of the second stroke was rotated randomly by various angles ranging from -30° to 30° and displayed on a monitor. Older adults were poorer in discrimination than young adults. In both age groups, the felt hand direction was shifted toward the seen cursor direction (i.e., visual capture) by approximately 25% to 30% of the rotation of the visual feedback. Older adults also showed an enhanced visual capture. The results suggest that both the increased sensory noise and the increased assimilation of the bimodal information cause the reduction of discrimination capability in older adults. These findings provide underlying reasons for age-related changes in learning a new visuo-motor transformation.

1. Introduction

Humans monitor their own actions multimodally. For example, visual and proprioceptive information is used to monitor the movements of the hand. However, when actions involve the use of tools such as a lever or a computer mouse, vision typically refers to the effective part of the tool (the tip of the lever or the cursor on the monitor), and proprioception to the hand, both operating at different locations. Here we investigate the individual's capability in discriminating movement directions of the hand and a cursor presented on a monitor, indicated by the 2 sensory modalities, and their age-related variation.

Typically, visual and proprioceptive signals about the hand-position are not identical, but tend to drift apart (Smeets et al., 2006). Nevertheless, they are integrated to obtain a single estimate of the position of the hand (Van Beers et al., 1999). In case of discrepancy (e.g., due to a visual perturbation), adaptive changes bring the 2 sources in line again (Van Beers et al., 2002). Integration is obviously an appropriate way of dealing with bimodal spatial information as long as it refers to the same object (Bedford, 1995).

When a tool is used, proprioception and vision signal different positions of different objects. The relation between them reflects the kinematic transformation of the tool. An example is the control of the cursor position on a monitor by moving the hand appropriately. Actions of this type require discrimination rather than integration of bimodal spatial information as a prerequisite to acquiring an internal representation of the kinematic transformation of the tool. To study this type of adaptation, visuo-motor rotations have become a well-established paradigm (Cunningham, 1989).

Recent evidence reveals that older adults are poor in adaptation to such visuo-motor rotations (Bock, 2005; Heuer and Hegele, 2008; Heuer et al., in press). Especially, their capability to acquire explicit knowledge of the visuo-motor rotation declines. What underlies these age-related changes, however, is not well understood. In an attempt to explore their underlying mechanisms, we modify the visuo-motor rotation paradigm to study the discrimination of the directions of hand and cursor movements. In particular, we test the hypothesis that this particular discrimination is poorer at older adult age. As a consequence, acquisition of explicit knowledge of directional differences would be impeded.

The hypothesis of poor discrimination of hand and cursor directions at older age is suggested by both psychophysical and neurophysiological findings. More specifically, these findings suggest that visual and proprioceptive spatial information lose distinctiveness for at least 2 reasons. First, declining sensitivity in elderly subjects has been shown psychophysically both for visual perception (Betts et al., 2007) and proprioception (Goble et al., 2009). This is consistent with the hypothesis of increasing noise in neural functioning (Welford, 1981). Second, there is strong

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evidence of neural dedifferentiation in aging, so that different mental operations come to rely more and more on common neural substrates (e.g., Carp et al., 2011; Liang et al., 2010). Thus, with concurrent bimodal spatial information assimilation could contribute to an age-related decline of discrimination capability. In particular for visual and proprioceptive information, an attractive effect of vision is known as visual capture (Hay et al., 1965). Visual capture is not necessarily restricted to situations in which vision and proprioception refer to the same object. For example, a seen hand optically superposed on an amputated arm results in felt movement of the phantom when the healthy arm is moved (Ramachandran et al., 1995). Thus, visual capture might also shift the felt direction of hand movement toward the seen direction of cursor motion.

Therefore, we assessed the general discrimination performance by means of standard psychophysical methods on one hand, and quantified the effect of the visual capture by means of a new indirect measure on the other hand.

2. Methods

2.1. Participants

Twenty young adults (mean ± SD, 26.0 ± 3.6 years; range, 18–31 years; 8 males and 12 females) and 20 older adults (mean ± SD, 60.0 ± 4.4 years; range, 53–67 years; 10 males and 10 females) participated in the study. All participants were right-handed. They filled in a health history questionnaire to exclude those with a history of stroke, arthritis, or other neurological or movement impairments, and gave written informed consent before participation. The study was conducted in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and with general approval of the Institutional Review Board of Leibniz Research Centre for Working Environment and Human Factors.

Young and older participants were compared on 2 subtests of the German version of the Wechsler Adult Intelligence Scale (Tewes, 1991): the Digit Symbol Test, a test of perceptuo-motor processing speed, and the Vocabulary Test, a test of culturally mediated knowledge. Consistent with typical findings, the average score on the Digit Symbol Test was higher for the young adults (mean ± SD, 61.2 ± 13.5) than for the older adults (53.4 ± 13.7), but the difference only approached statistical significance [$t(38) = 1.8$, $p < 0.1$]. The results of the Vocabulary Test were similar in the 2 groups [young, 22.9 ± 4.8; old, 21.1 ± 3.3, $t(38) = 1.3$, $p > 0.1$].

2.2. Apparatus

The experimental setting is shown in Fig. 1A. Participants were seated at a table on which a 22-inch liquid crystal display monitor (Samsung SyncMaster2233, refresh rate 100 Hz) was placed in approximately 60 cm distance from their eyes. The monitor was covered by a large black circular screen (72 cm in diameter) with a semi-circular window (32 cm in diameter) in its center, through which the participants could see the computer monitor.

A digitizer tablet (Wacom Intuos 4XL) was placed on the table between the participants and the monitor. The participants held a stylus in a manner similar to holding a pen for handwriting. Movements of the stylus on the tablet and those of a cursor displayed on the monitor had a 1-to-1 ratio with respect to distance. An opaque board placed above the participants' arm blocked their view of the hand movements. The starting position of the cursor on the monitor was aligned with the participants' median plane. The *X*- and *Y*-positions of the tip of the stylus were recorded at 133 Hz with a spatial resolution of 0.005 mm.

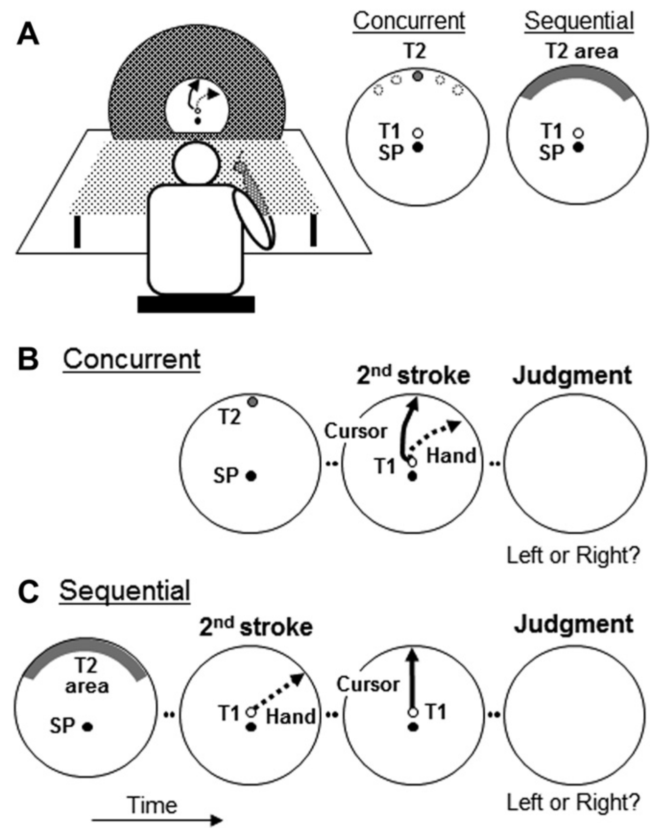

Fig. 1. The experimental setup and target locations are shown in (A). SP, starting position; T1, first target; T2, second target. The visual feedback of the second-stroke movement was displayed simultaneously with hand movements in the concurrent condition (B) or after the movement in the sequential condition (C).

2.3. Design and procedure

Participants performed 3-stroke arm movements with their right hand in the horizontal plane. To examine the effect of concurrent processing of the 2 sensory modalities (vision and proprioception) on the discrimination of hand and cursor directions, participants underwent a concurrent condition (Fig. 1B), in which the visual feedback was presented simultaneously with the hand movement. As a control to the concurrent processing of visual feedback, a sequential condition was also introduced (Fig. 1C), in which the visual feedback was presented after the hand movement.

2.3.1. Starting position and targets

Target locations for both concurrent and sequential conditions are illustrated in Fig. 1A. The first target (T1, 1.4 cm in diameter) was located in the center of the semi-circular window. The starting position (SP; 1.2 cm in diameter) was located 3 cm below the T1. The locations of the SP and T1 were the same for both the concurrent and sequential conditions.

In the concurrent condition, 1 of 5 possible second targets (T2, 1 cm in diameter) was presented. The targets were located 15 cm from T1, just above it (the gray circle in Fig. 1A) and at 15° and 30° left or right of the center (open circles in Fig. 1A). The participants made 3-stroke movements from the SP to T1 (first stroke), then to T2 (second stroke), and subsequently back to T1 (third stroke).

In the sequential condition, no specific T2, but an area to which second strokes were to be made, was displayed (Fig. 1A, T2 area). The T2 area was on an invisible circle with a radius of 15 cm around T1, and the area spanned from 45° left to 45° right of the central location. The participants made 3-stroke movements from the SP to